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It seems to be also entirely proper to emphasize my personal opinion as to future researches of the kind, which is, that such future researches should be carried on by photography; and this for two reasons—*first*, the labor of skilled and faithful workers will thus be available for other investigations, *second*, the "photographic" Milky Way, as we may call it, can be mapped again and again during the time required to make a single complete drawing. It must be recollected, however, that both the drawings last mentioned were commenced and well under way before it was known how simply and satisfactorily such representations could be made by the camera.

LICK OBSERVATORY, December, 1893.

# THE DISINTEGRATION OF COMETS.

BY PROFESSOR H. A. NEWTON.

[Professor H. A. NEWTON of Yale University recently delivered the following extempore address before the American Philosophical Society. It is of special interest, since no one is better qualified than Professor NEWTON to speak upon questions relating to meteors and comets.]

"I have to apologize somewhat in that I came to the rooms not expecting to speak to you. I have, however, one point which I think will interest the members of this Society if they will give me a few minutes to develop it, and that is, the force which acts on the small bodies sent off from comets and which form our shooting stars.

"There are in the comets so many questions that we cannot answer, so many curious and wonderful phenomena that are unexplained, that I am sure you will accept any explanation of any of them that seems plausible, as a matter of interest. From a comet there is continually driven off matter forming the tail, a light substance, and astronomers are agreed that the force that acts on the matter which forms the tail is a repulsive force from the Sun acting inversely as the square of the distance, the force of the repulsion being greater than that of attraction.

"Not only is this true, but different parts of that tail are acted upon by repulsive forces of different powers; otherwise the tail would form across the sky a single line instead of a broad, expanded mass of light such as we see. From the comet, however, there are driven off also, or there are separated, other things entirely distinct from the tail, small bodies, which are not thus driven away, which are not visible, but follow along closely in the path of the comet, and whenever the occasion comes, that is when we go through a group of them, those give us our shooting stars.

"The BIELA comet, in the period about 1840, passed near to *Jupiter*. At that time it was turned pretty sharply out of its orbit, the inclination of the orbit being turned several degrees, and the node being carried forward also several degrees, represented by several days in the time at which we crossed the path of the comet.

"After 1840 the bodies which formed the meteors that were met in 1872 and in 1885 were separated from one or other parts of the BIELA comet. I say after 1840, because if they had been separated earlier they would have given us a different radiant in the skies, the one given by the BIELA meteors of 1838. The radiant was changed, the node was changed, all to correspond to the new orbit, and these bodies could not have been turned in that way had they been before scattered, because the force that acted on them, the attraction of *Jupiter*, would have scattered the group instead of giving us that single compact group through which we passed in 1872 and 1885 in the course of four or five hours, and the bulk of them even in two hours.

"In 1872, the comet was something like 200,000,000 miles away from the bodies that we met as we passed through them on the 27th of November, giving us a brilliant shower. Thirteen years later we passed through the group again, and then we were something like 300,000,000 miles ahead of the comet. So that some of the particles leaving the comet between 1840 and 1885 had gained, and others between 1840 and 1870 had fallen behind.

"What should separate those particles? What are the forces which carried off those particles so many miles—200,000,000 miles on the one hand and 300,000,000 miles on the other in round numbers? The force that acts on them must be a force acting in one plane, that is, the plane of the orbit of the comet. Any force acting in other planes would have scattered the group, and we would not have met them as a single definite group at the times named; but if it acts in the plane, only scattering them on the plane, they would be together as we saw them.

"In that plane it must be either an impulsive force acting once or it must be a constant force acting continually. The only bodies in that plane are the comets and the Sun, and if the force is a continuous force it must be from the comet or from the Sun. It is almost inconceivable to suppose that the comet could have sent them off, either impulsively or continuously, in such a way as to give us the distance of 200,000,000 and 300,000,000 miles in the course of thirty years; it would require far more than any velocity that we can give in our terrestrial experiments, and we have no reason to suppose that there is any such power of impulsion. Moreover, if the impulsion came from the comet they would go in all directions and their character, as being in a plane, would have been entirely lost.

"We are then thrown back on this one hypothesis, that the Sun is the source of that force. In other words, we are led to extend the idea that I gave you in the beginning, and which is accepted by astronomers, that the material which goes off from the comet, after it leaves it, is subject to a force like that of attraction but differing in its intensity. In the case of the tail, it is a repulsive force. To satisfy these conditions of separation, part in one direction and part in the other, from the comet, we must have an attraction in the one case exceeding the attraction of gravitation, and in the other an attraction less than the attraction of gravitation. In other words, these little bodies of hard matter that go off from the comet and follow very nearly in its train are acted on not in proportion to this mass like the force that acts on the planets in their orbits.

"I see no escape, myself, from this conclusion. What it means I must leave to you to decide. Our experiments make it very improbable that the attraction of matter differs in any way from proportion to the mass. It looks to me as though the more natural explanation is that, in some way, the materials which go off from the comet carry with them a load of electricity, or something of that kind, by which they have a permanent repulsion or permanent attraction sufficient to change the orbit altogether, not in kind, but in a steady change, throwing them into a new orbit with a new period, and thus scattering them.

"What that added force must be we cannot very well tell, because it differs according to the place in the orbit where the disintegration takes place. If that disintegration takes place near the Sun, it is one thing; if it takes place near *Jupiter*, it is another. It looks more to me as though there was a disintegration all along the line of the comet's orbit, giving us small particles with all sorts of loads of electricity and all sorts of differences of central attraction and differences of orbits, and thus they get widely scattered so as to give us the showers a long distance from the comet itself. The amount of this change would have to be something like the tenth part, possibly, or something less than that. I should think that all the phenomena could be explained by a change amounting to one-tenth of the attraction; that is, if the small particle carries a load of electricity such as to diminish the attraction to say nine-tenths of the original attractive force of the Sun, or increase it to eleven-tenths, it will explain the phenomena.

"If that is the explanation, we come to this further conclusion of interest, that the space through which these comets move is not such that the electricity which the particle carries can be lost. Another practical point would be that, in the discussion of the separation of these comet masses that through the telescope we see going off as the comets pass the Sun, there might fairly be introduced an unknown correction of the force of central attraction."

"A MEMBER: 'Have you gentlemen, who have made a study of this very interesting subject which you have been discoursing on, arrived at any hypothesis as to what broke up the BIELA comet?'"

"PROF. NEWTON: 'I can only answer that a working hypothesis, in my own mind, is that a mass not surrounded by an atmosphere, coming down from the cold into a warmer region near the Sun, becomes heated up, and in that heating there is a disintegration going on. If you put the pieces of a meteorite into a vacuum and heat them you will get gases that will be something like those which are thrown off from the tail of a comet, and the comet coming down near the Sun, with the hot, scorching effect entirely undiminished by a thick atmosphere, would have pieces broken off, giving fresh surfaces. An immense amount of action of some sort follows, and those pieces would naturally go off under such excitement carrying with them, as I conceive, a load of electricity. The process goes on in almost all our comets. It is not in *Biela* alone that we see comets going off to pieces. Scores of comets have shown that same breaking up under the telescope.'"